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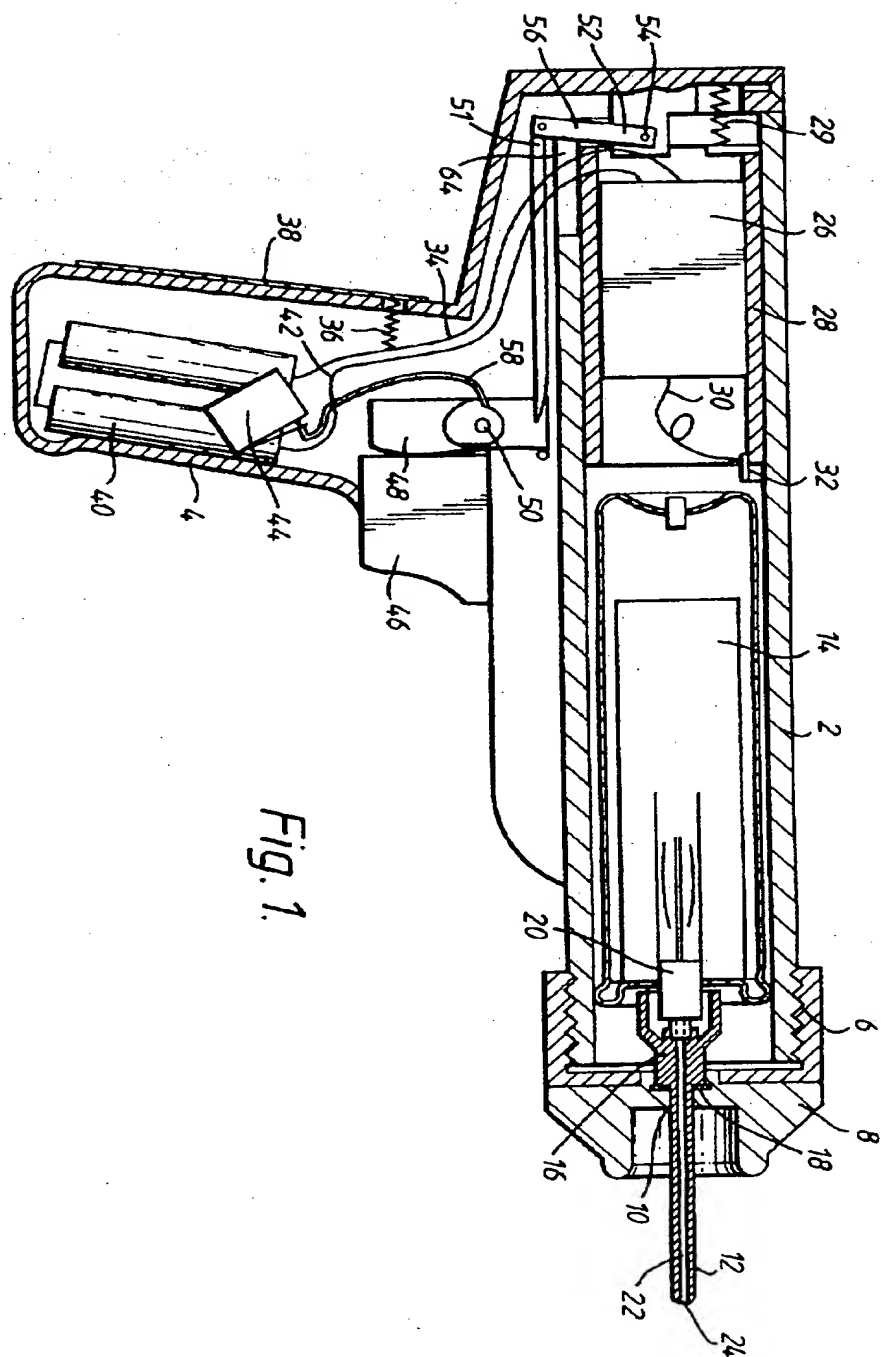
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(54) **Electrostatic spraying device and method.**

(57) An electrostatic spraying device in which liquid emerging from an outlet (24) of the device nozzle (12) is subjected to an electrical field sufficiently high for the liquid to be drawn from the outlet as one or more ligaments which break up into charged droplets to form the spray. In order to provide shock suppression, the electrical field is produced by means of high voltage circuitry having a bi-polar output with a frequency no greater than 10 Hz.

EP 0 468 736 A1



The present invention relates to electrostatic liquid spraying devices.

On the whole, such devices use a direct current high tension source in order to electrostatically charge the particles of the liquid spray. However, it is known from US Patent 1958406 to use a source of alternating potential in conjunction with an electrostatic spraying device but there is no explicit teaching as to the frequency employed. The general tenor of the disclosure implies that the frequency utilised is mains frequency, ie. 60 Hz in the USA.

It is also known from UK Patent No 2128900 to provide a lever-operated spraying device in which an atomised spray is produced from a nozzle by squeezing the lever. This device includes a needle electrode positioned at or adjacent the nozzle and high voltage is applied to the needle electrode to ionise the spray emerging at the outlet of the nozzle. In one embodiment, the voltage generator is piezo-electric and the action of alternately squeezing and releasing the lever results in high voltage pulses of successive opposite polarity being applied to the electrode. During the squeezing action, spray is produced and the resulting droplets are charged by corona discharge from the electrode. During the release action, no spray will be produced but the high voltage at the needle may reverse in polarity to produce a corona discharge which may serve to eliminate or modify static when the device is used in certain applications.

The present invention resides in the recognition that certain advantages can be derived from the use of alternating potential sources by appropriate selection of the frequency of the source.

One of the problems of using electrostatic spraying apparatus is to prevent the operator from experiencing electrical shocks which may be perceived as unpleasant or may expose the operator to risk. For example, where a direct current electrostatic spraying device which is wholly hand held is used (and hence where no other path to earth exists other than through the operator), if the operator is or becomes substantially isolated from earth (for instance, as result of standing on a synthetic fibre carpet or wearing shoes having soles of insulating material), during spraying charge will accumulate on the operator and, if the operator subsequently touches an earthed conductor, he/she will experience an electrical shock. Such electrical shocks can expose the operator to risk either through the magnitude of the electrical discharge itself or as a result of an involuntary reaction on the part of the operator in response to the electrical discharge.

According to the present invention there is provided an electrostatic spraying device adapted for shock suppression comprising a nozzle, means for supplying liquid to the nozzle, and high voltage circuitry arranged so that, in use, liquid sprayed in atomised form from the nozzle is electrostatically charged,

the high voltage circuitry providing an output which alternates between opposite polarities with a frequency no greater than 10 Hz so that the spray is alternately charged positively and negatively.

Preferably the frequency is no greater than 3 Hz, more preferably no greater than 1 Hz.

Preferably the frequency is at least 0.05 Hz, more preferably at least 0.2 Hz.

In practice, the effectiveness of the shock suppression will to some extent be dependent on the nature of the liquid to be sprayed and the flow rate of the liquid. A frequency in the range of 0.2 to 3 Hz will usually cater for most circumstances. Frequencies less than 0.2 Hz may however be satisfactory provided that the resistivity of the liquid is not low and provided that the flow rate is not high. For example, in subjective tests carried out, it was found that using a liquid having a resistivity of about $5 \times 10^6 \Omega \text{ cm}$ at a flow rate of 0.8 ml/min gave a very slight shock at a frequency of 0.175 Hz whereas using the same liquid at a flow rate of 0.3 ml/min, the frequency could be reduced to 0.125 Hz before a slight shock of subjectively the same magnitude was experienced. Similarly, using a liquid having a resistivity of $1.4 \times 10^7 \Omega \text{ cm}$ and a flow rate of 0.3 ml/min, the frequency could be reduced to about 0.05 Hz before a shock of subjectively the same magnitude as that referred to above was experienced.

Thus, by appropriate selection of the frequency, it is possible to eliminate the sensation of electrical shock by the operator or at least reduce the sensation to a level at which the risk of an accident as a result of an involuntary reaction by the operator is reduced.

The high voltage circuitry may comprise two high tension generators producing outputs of opposite polarity and switching means arranged to render the generators effective alternately to effect charging of the liquid, the frequency of switching being no greater than the frequencies specified above.

Alternatively, it is contemplated that the high voltage circuitry may comprise a single high tension generator producing a bi-polar output.

According to a feature of the present invention there is provided the high voltage circuitry comprises a voltage multiplying circuit having:

input terminal means for connection to a pulsed voltage source;

output terminal means for providing an output voltage which is bipolar and is a multiple of the voltage applied to the input terminal means;

two parallel sets of serially connected capacitors connected between the input and output terminal means; a plurality of paired bi-directional switches interconnecting the sets of capacitors in such a way that each junction between successive capacitors in one of said sets is connected to a pair of said switches which couple the junction to opposite sides of a capacitor of the other set; and

means for effecting alternating operation of the

switches of each pair in phased relation with the pulsed voltage source and for cyclically varying such phased relation to cause the output voltage at the output terminal means to alternate between opposite polarities.

Preferably the device is adapted to accommodate one or more low power batteries which may be of the rechargeable type, means being provided for producing from the battery supply voltage a pulsed voltage for application to the input terminal means of the voltage multiplying circuit. Means may also be provided for effecting a preliminary multiplication step so that the magnitude of the pulsed voltage applied to the voltage multiplying circuit is a multiple of the battery supply voltage.

Conveniently, the bi-directional switches are self-commutating, i.e. when triggered into a "on" state they do not require the triggering signal to be maintained in order to remain on but will remain on until current flow through the switch ceases.

In a preferred embodiment of the invention, the switches are constituted by triacs which are self-commutating devices.

Advantageously, the triacs are of the known type which can be triggered by optical signals.

It is preferred that a device according to the invention is operated at a frequency somewhat lower than 10 Hz because frequencies at the higher end of the specified range tend to give rise to contamination problems. It would appear that at the instant of switch-over, a situation exists in which the nozzle is at for example a negative potential and is "looking" at a receding spray cloud of positive polarity. In such circumstances, it would appear that there is a tendency for the receding positive spray to be "pulled back" towards the nozzle with the risk of contamination. Also as the frequency is increased the risk increases of collision between a newly issuing spray cloud of one polarity and a receding spray cloud of the opposite polarity, and hence the formation of larger, discharged particles. For these reasons, it is contemplated that optimum operation of the device will be at a frequency no greater than 5 Hz.

The device may be in a form suitable to be held in the hand and may comprise a housing including a hand grip portion, the housing mounting the nozzle and accommodating the high voltage circuitry and a power source. The hand grip portion conveniently includes a trigger action for turning the spray on and off.

An embodiment of the invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a schematic view in cross section of an electrostatic spray gun embodying the invention;

Figure 2 is a schematic diagram of the high voltage circuit of the gun of Figure 1;

Figure 3 is a cross section of a container for use in the gun of Figure 1;

Figure 4 shows one embodiment of a schematic voltage multiplying circuit for use in generating a bi-polar high voltage output; and

Figure 5 shows another embodiment of a schematic voltage multiplying circuit for use in generating a bi-polar high voltage output.

The invention may be embodied in any shape convenient to the purpose to which it is to be put. The embodiment illustrated is in the form of a spray gun.

The spray gun illustrated in Figure 1 has a body member 2 and a hand grip 4. The body member 2 is in the form of an tube of insulating plastics material. The body member is externally threaded at its end 6 to receive an end cap 8, which may also be of plastics material selected from the same group. Alternatively the end cap may be of a less insulating material, for example Tufnol Kite brand. The end cap 8 has a central aperture 10 through which, in use, a nozzle 12 projects. Means, in the form of a container 14, is provided for delivering liquid to be sprayed to the nozzle. The nozzle 12, which is permanently attached to the container 14, has a shoulder 16 which is received by a recess 18 on the inside of the end cap, thereby to locate the nozzle accurately centrally of the end cap. The container may be replaced by removing the end cap.

The container is pressurised by a liquefied propellant which is separated from the liquid to be sprayed by a metal foil sack 19 (Figure 3). The supply of fluid to the nozzle 12 is switched on and off by a valve 20 with which a passage 22 in the nozzle communicates. As in the case of an aerosol can, pressing the valve 20 relatively towards the container 14 opens the valve allowing liquid to be propelled from the container by the pressurised propellant and into the passage 22 of the nozzle. An internal restriction in the container 14 limits the flow rate to a low value, e.g. 1 cc per minute and so that the liquid arrives at the outlet 24 of the nozzle at very low pressure which is not sufficient to cause any or significant atomisation in the case of non aqueous liquids, or so as to cause only poor atomisation in the case of aqueous liquids. The nozzle may be insulating or semi insulating. It is preferred that the nozzle is insulating being made from a material having a resistivity greater than 10^{14} ohm cm. Examples of such materials are ABS, polypropylene, polyethylene, polyvinyl chloride, acrylic, polycarbonate, acetal. Insulating nozzles rely on the liquid to be sufficiently conducting that the voltage drop caused in use by the resistive effect of the liquid is not so great as to reduce the voltage at the nozzle to a value which spoils the quality of, or prevents, spraying. In cases where the liquid is has too high a resistivity, the nozzle may be made from a more conducting material so that it acts as a resistor in parallel with the resistance presented by the liquid. In the extreme case of a highly

insulating liquid, the material of the nozzle may have a bulk resistivity of 10^7 ohm cm, the resistivity normally being above this value. Ceramic materials may be made with such values of resistivity. The container 14 is conducting, in this example.

In the example illustrated a single filament or ligament of liquid issues from the tip of the nozzle. In other examples, the nozzle may be annular or in the shape of a plane blade so that a plurality of ligaments of liquid issue therefrom.

At the end of the body member 2 remote from the nozzle 2, high voltage circuitry 26 is situated in a tubular carriage 28. The carriage 28 is slidable in the body member 2 and is biased away from the end cap 8 by a tension spring 29. The circuitry 26 has a high voltage output pole 30 connected to a contact schematically indicated at 32 for contact with the conducting container 14. The output pole 30 provides an alternating output, the frequency of which is no greater than 10 Hz. The other high voltage output pole is electrically common with a low voltage supply lead 34 and thus connected via a resistor 36 to a contact strip 38 on the exterior of the hand grip 4. The low voltage supply lead is connected to one pole of a battery 40. The other pole of the battery is connected to the circuitry 26 by another low voltage supply lead 42 via a microswitch 44.

The valve 20 is opened, in use, by relative movement between the container 14 and the body 2, the nozzle 12 remaining fixed in relation to the body. Movement to operate the valve is applied to the container by movement of the carriage 28. To this end, the grip 4 has a trigger 46 which when squeezed operates on one end of a lever 48 which is pivotally mounted at 50. Movement of the lever 48 is communicated by a link 51 to a further lever 52 which is pivotally mounted at one end 54. A central portion 56 of the lever 52 bears on the end of the carriage 28 remote from the container 14 so that when the trigger 46 is squeezed, resulting movement thereof is translated into movement of the carriage, and thus the container, towards the nozzle, so opening the valve 20. As this happens a linkage 58 operates the microswitch 44 so that power is supplied to the circuitry 26. The high voltage output from the circuitry 26 is thus applied to the container and so to the liquid therein. The high voltage is thus conducted to the tip of the nozzle, via the liquid in the case of an insulating nozzle, where the electric field strength is sufficient to produce a charged spray. In the case of a semi insulating nozzle, the nozzle itself contributes to the conduction.

The spray may be formed preponderantly by electrostatic forces, suitable liquids for such operation preferably having a resistivity in the range 1×10^5 to 5×10^{10} ohm cm in the case of non-aqueous liquids. In the case of more conducting liquids and aqueous liquid systems, a jet may be produced by hydraulic pressure, even in the absence of the high voltage,

which jet breaks up into coarse droplets. The addition of the high voltage creates an electric field which accelerates the jet (as in the case of more resistive liquids) and improves the spray by decreasing the droplet size and, since like charges repel each other, spreading the spray out into more of a cloud.

In use the grip is held in a hand and the trigger is squeezed as explained above. The hand contacts the conducting strip 38 to provide an earth return circuit. It will be understood that the earth return path is optional but, when present, serves to provide capacitance with respect to earth. The high voltage circuit is shown schematically in Figure 2. The contact strip 38 is connected via a person (the operator of the gun) to ground. In normal use the current through the operator is too small to feel or to pose any kind of danger. The circuitry 26 comprises a pair of high tension generators 80 connected in a circuit with the battery 40 and microswitch 44. Each generator 80 is also connected via lead 34 and a resistor 36 to the contact strip 38. The generator 80 are arranged so that they produce at outputs 82, 84 a dc high voltage typically of the order of 15kV of opposite polarity to one another and the outputs 82, 84 are connected via gating circuitry 86 to the output lead 30, the gating circuitry 86 being arranged to switch between the generator outputs 82, 84 at a rate which will provide an alternating high voltage output of frequency up to 10 Hz and ranging typically ranging between +15kV and -15kV. The output lead 30 is connected to the container 14 and so via the liquid therein to the tip of the nozzle 12. Liquid issues from the nozzle in the form of a filament or ligament which breaks up into a spray of charged droplets 66. Successive spray clouds of droplets will be oppositely charged by the alternating generators 80. The droplets are attracted to an earthed object 68, which may be an intended or unintended target. Earth may be used to complete the circuit through the operator.

If, when the apparatus is being used, the operator is substantially isolated from earth and touches an earthed conductor, the use of an alternating high voltage prevents the build-up of a charge on the operator of sufficient magnitude to be experienced as a shock or, if any shock is experienced, it will not be one which causes a person to react involuntarily to a significant extent. Also by limiting the frequency of the alternating potential so that it is no greater than 10 Hz (more preferably no greater than 3 Hz), undesirable contamination resulting from the "pull back" effect previously mentioned can be reduced or minimised.

In the embodiment shown in Figure 2, the high voltage circuitry comprises two high voltage generators producing opposite polarity outputs. Figure 4 illustrates diagrammatically a bi-polar high voltage circuit which may form the voltage generator illustrated in Figure 1. In this embodiment, the production of a bipolar high voltage output is effected by

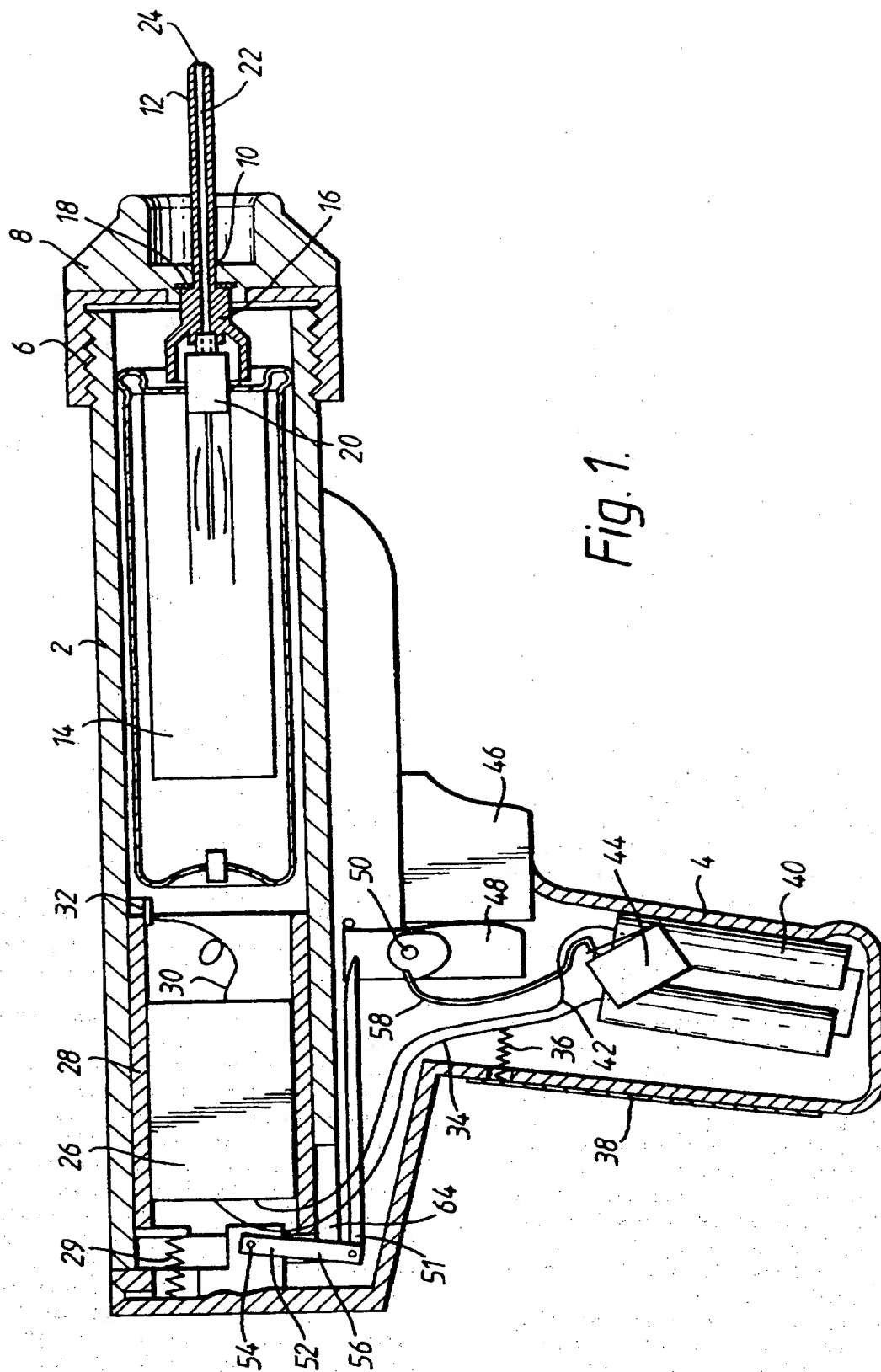
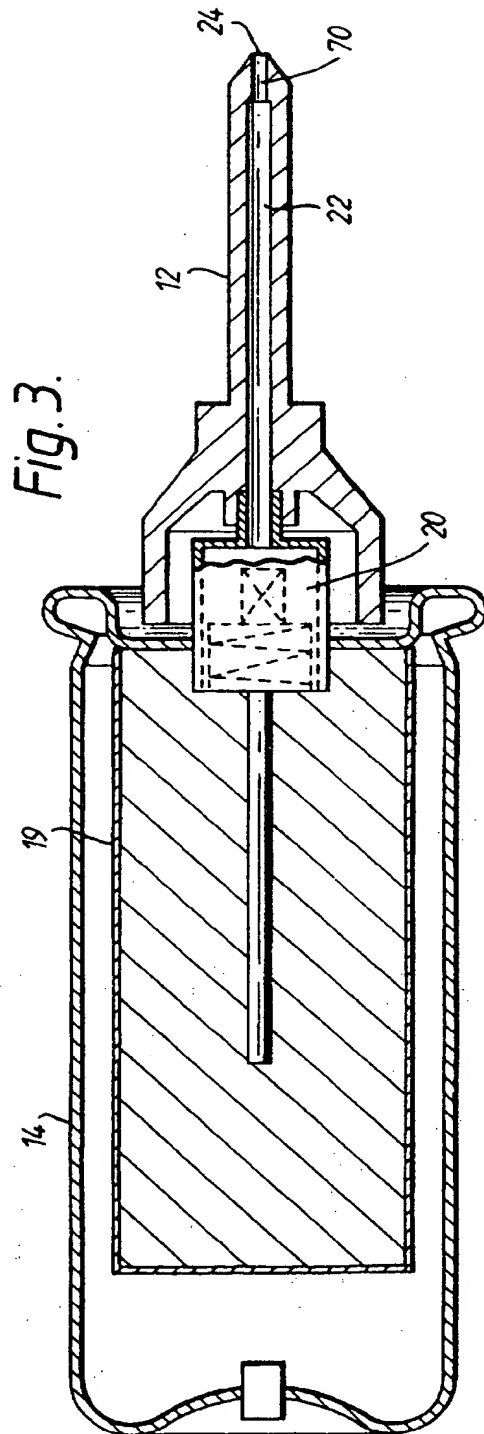
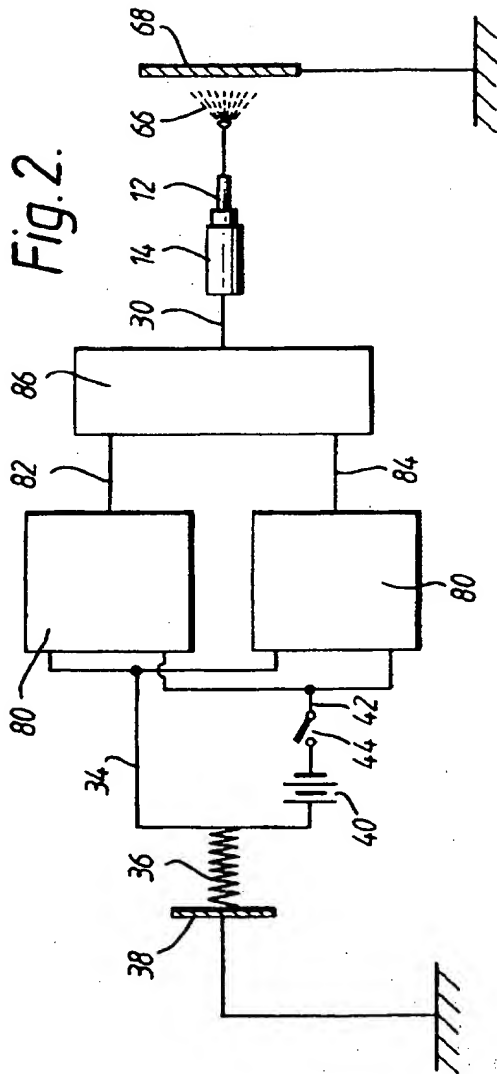


Fig. 1.



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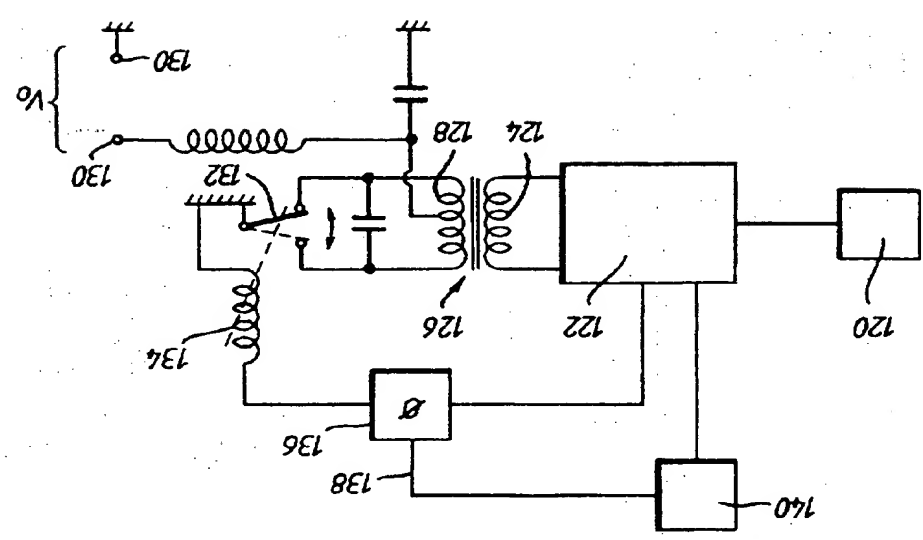


Fig. 5.

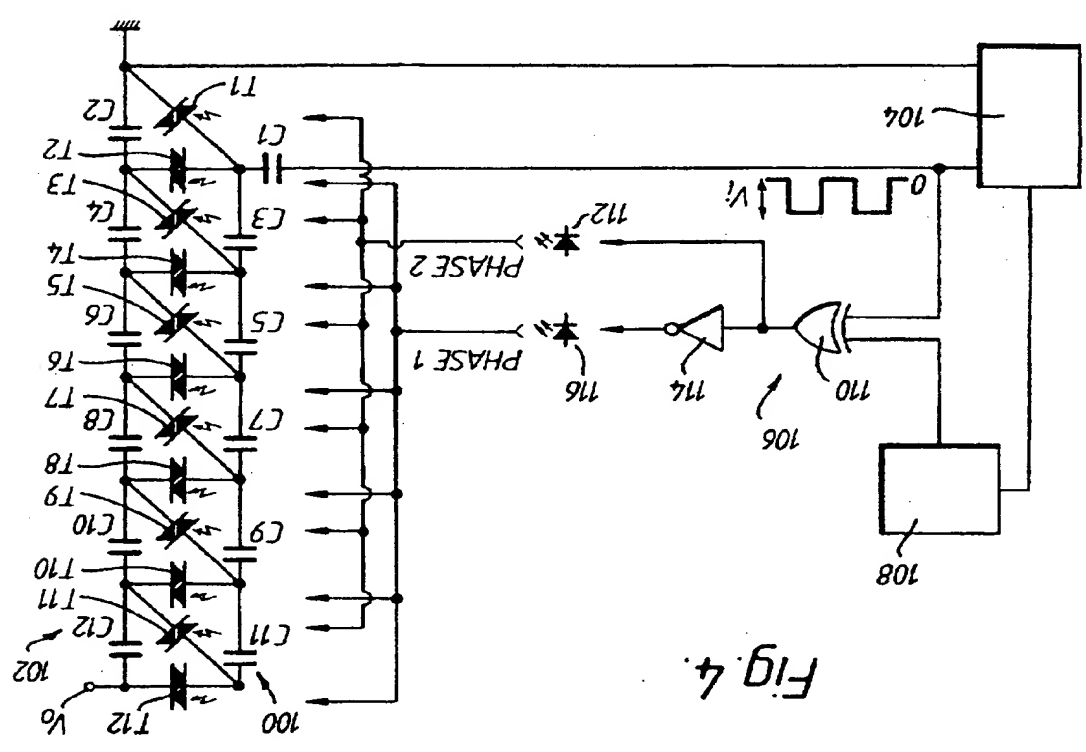


Fig. 4.